

Research Article

The effects of subsampling and between-haul variation on the size-selectivity estimation of Chilean hake (*Merluccius gayi gayi*)

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ABSTRACT. Using the data collected in a size selectivity experiment on Chilean hake (*Merluccius gayi gayi*) carried out in 2000, the selectivity parameters for four codend mesh sizes (100, 110, 130, and 140 mm of mesh size opening) were estimated and modelled by the SELECT model. These analyses included considerations of the sampling proportions of the catch in the codend and cover. Furthermore, the analyses took into account between-haul variation. The l_{50} values were 30.8, 29.9, 30.0, and 41.2 cm of total length, respectively, values lower than the estimates obtained from previous studies. The contribution of explanatory variables to the selectivity model was also tested in order to determine the role of mesh size, catch size (in number), and towing speed. Increases in catch size and in towing speed were accompanied by decreases in the l_{50} estimates. These results demonstrate how incorporation of subsampling effect and explanatory variables to model between-haul variation can improve selectivity estimates and management of a valuable resource.

Keywords: size selectivity, mesh size, subsampling effect, between-haul variation, *Merluccius gayi gayi*, Chile.

Los efectos de submuestreo y variación entre lances en la estimación de la selectividad a la talla de la merluza común (*Merluccius gayi gayi*)

RESUMEN. Usando los datos recolectados en un experimento de selectividad a la talla de merluza común (*Merluccius gayi gayi*) realizado en el año 2000, se estimaron y modelaron los parámetros de selectividad para copos de cuatro tamaños de malla (100, 110, 130 y 140 mm de tamaño de malla interno) mediante el modelo SELECT. Los análisis incluyeron consideraciones de las proporciones de muestreo de la captura en el copo y en el cubrecopo. Además, los análisis tuvieron en cuenta la variación entre lances. Los valores de l_{50} fueron 30,8; 29,9; 30,0 y 41,2 cm longitud total respectivamente, valores menores que los obtenidos en estudios previos. Se probó también la contribución de variables explicatorias al modelo de selectividad, para determinar el aporte del tamaño de malla, el volumen de captura (en número) y la velocidad de arrastre. Los incrementos en el volumen de captura y en la velocidad de arrastre produjeron una disminución en los estimados de l_{50}. Estos resultados demuestran cómo, a partir de la incorporación del efecto de submuestreo y de variables explicatorias al modelo con variación entre lances, es posible mejorar los estimados de selectividad y manejar un valioso recurso.

Palabras clave: selectividad a la talla, tamaño de malla, efecto de submuestreo, variación entre lances, *Merluccius gayi gayi*, Chile.

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INTRODUCTION

Chilean hake (*Merluccius gayi gayi*) occurs along the coast of Chile between 23º and 47ºS at depths from 50 to 500 m. It is the main demersal species caught along the central coast. The biomass of this resource decreased dramatically as a consequence of natural (cannibalism and predation) and fishing mortality from 2002 to 2005 and the current stock assessment indicates that it is overexploited (SUBPESCA, 2010). The proportion of fish below the size-at-maturity has increased since 2004 (more than 70% of the catches) and the present spawning biomass is below the limit reference level of 20% established for the fishery (SUBPESCA, 2010).

Regulation of mesh size is one of the most common management measures in fisheries. Specification and use of an appropriate mesh size can contribute to increases in the size of first capture and can reduce the mortality of smaller fish. Only one experiment on size selectivity has been performed for the Chilean hake trawling fishery over the last decade. Gálvez *et al*. (2000) analysed the selectivity of four mesh sizes (100, 110, 130 and 140 mm) using the covered codend method and the results were later published by Gálvez & Rebolledo (2005). These authors estimated similar l_{50} values among the different mesh sizes used, although the escape proportions increased with increasing mesh size. These results were compared with different selectivity studies carried out in Gadiformes (Fig. 1). A linear relation was found for this group of fishes between the mesh size and the 50% retention length, with a slope of ~0.4. Because Gálvez & Rebolledo (2005) found a lower value of the slope for this relationship (~0.1), the procedures were reviewed. In fact, the sampling proportions of the codend and cover were not considered in their analysis. Subsampling is necessary when the catch is so large that it is not possible to measure every single individual (Wileman *et al.*, 1996). The effect of subsampling can be incorporated in two ways: (i) expanding the sample to the total catch or (ii) correcting the estimated parameters by a subsampling factor. Millar (1994) points out that the second case is preferable because it uses raw (unscaled) data and thereby ensures statistical rigour.

Replicate hauls using the same trawl and configuration indicate that codend selectivity changes from one haul to another. Fryer (1991) indicated that the between-haul variation could be due to a number of "uncontrolled" factors. Examples of such factors include the haul duration, catch size, fishing season and depth among others (O'Neill & Kynoch, 1996; Millar & Fryer, 1999; Fonseca *et al.*, 2007; Grimaldo *et al.*, 2008; Sala & Lucchetti, 2010).

The objective of this study was to estimate the selectivity parameters so as to account for subsampling proportions. Moreover, explanatory variables were added in order to incorporate the effects of between-haul variation. The resulting parameter values were compared with previous estimates.

MATERIALS AND METHODS

Selectivity experiments were conducted during March-April 2000 on board a stern trawler (41.7 m overall length; 1900 HP) in the central-southern area of Chile (between 34º50'-35º40'S). Hauls were made during daylight hours at depths from 90 to 260 m. The duration of each haul varied between 14 and 135 min. Towing speed fluctuated between 3.0 and 4.0 knots (3.4 knots average speed) (Table 1). The hauls were carried out using a 53-m headline and 37-m footrope Engel Balloon Trawl, with four experimental codends of 100, 110, 130 and 140 mm mesh size opening. The covered codend method was used to retain the fish that escaped through the meshes (Galvez & Rebolledo, 2005). A length-frequency dataset was obtained from 32 covered codend experimental hauls (Table 1).

The data from each of the two compartments (codend and cover) were analysed separately. The catch weight for each compartment *j* was estimated for each haul. In order to estimate the catch in numbers of Chilean hake, a length-weight function was applied based on data recorded by Lillo *et al.* (2001). The average specimen weight was then determined $\left(\overline{w}_j\right)$. The number of retained specimens by haul and compartment was obtained according to $N_j = \frac{W_j}{\overline{w}_j}$, where W_j is the catch weight in each compartment.

For each haul, the retention probability *r(l)* of the codend was modelled using a logistic curve: $r(l) = \frac{e^{v_1+v_2 l}}{1+e^{v_1+v_2 l}}$, where *r(l)* is the (conditional) retention probability of a fish of length *l* given that it entered the codend (Wileman *et al.*, 1996), and $v = (v_1 + v_2)^T$ is the vector of the selectivity parameters. The correction for the effects of subsampling was performed according to Millar (1994) who showed that for subsampled hauls $r'(l) = \frac{e^{v_1^*+v_2 l}}{1+e^{v_1^*+v_2 l}}$, where $v_1^* = v_1 + \ln(q)$ and

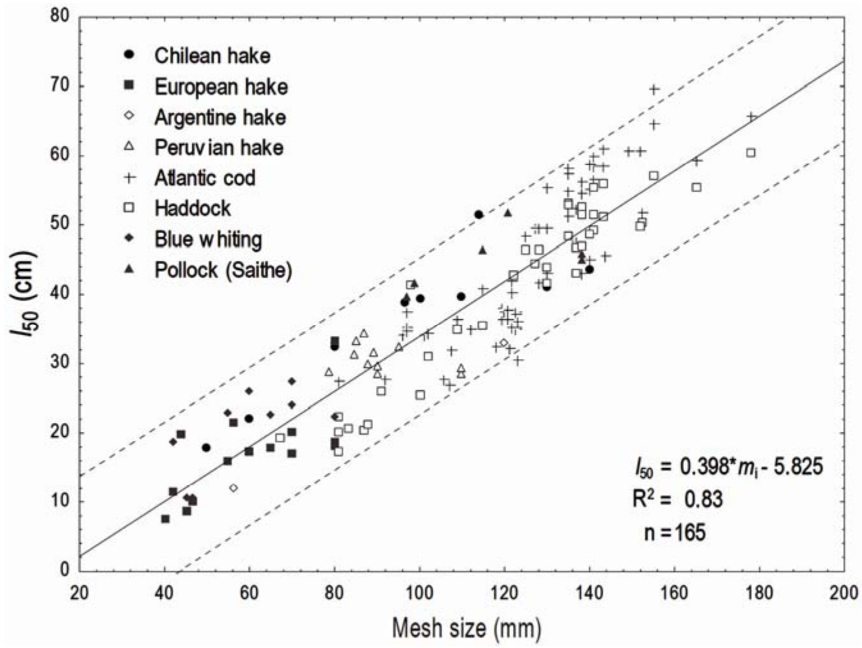

Figure 1. Estimates of l_{50} for some species of the Merlucciidae and Gadidae families as a function of mesh size. Chilean hake: Saetersdal & Villegas (1968); Arana (1970); Gálvez & Rebolledo (2005). European hake: Campos & Fonseca (2003); Campos *et al.* (2003a, 2003b); Deval *et al.* (2007); Lucchetti (2008); Sala & Lucchetti (2010); Tokaç *et al.* (2010). Argentine hake: Rojo & Silvosa (1970); Verazay *et al.* (1992). Peruvian hake: Salazar *et al.* (1996). Atlantic cod: Sakhno & Sadokhin (1982); Netzel & Zaucha (1989); Isaksen & Valdemarsen (1990); Isaksen *et al.* (1990); Hickey *et al.* (1993); Lowry *et al.* (1995); Huse *et al.* (1996); Tschernij *et al.* (1996); Halliday *et al.* (1999); Tschernij & Holst (1999); Blady & Zaucha (2000); Wienbeck & Dahm (2000); Halliday (2002); Madsen *et al.* (2002); Graham *et al.* (2004); He (2007); Grimaldo *et al.* (2008). Haddock: Sakhno & Sadokhin (1982); Robertson & Stewart (1988); Isaksen *et al.* (1990); Reeves *et al.* (1992); Sangster & Lehmann (1994); Halliday *et al.* (1999); Halliday (2002); Graham *et al.* (2004); He (2007); Grimaldo *et al.* (2008). Blue whiting: Campos *et al.* (2003a); Campos *et al.* (2003b); Sala & Lucchetti (2010); Tokaç *et al.* (2010). Pollock (saithe): Smolowitz (1983); Dahm (1998) and Graham *et al.* (2004).

Figura 1. Estimados de l_{50} para algunas especies de las familias Merlucciidae y Gadidae como función del tamaño de malla. Chilean hake: Saetersdal & Villegas (1968); Arana (1970); Gálvez & Rebolledo (2005). European hake: Campos & Fonseca (2003); Campos *et al.* (2003a, 2003b); Deval *et al.* (2007); Lucchetti (2008); Sala & Lucchetti (2010); Tokaç *et al.* (2010). Argentine hake: Rojo & Silvosa (1970); Verazay *et al.* (1992). Peruvian hake: Salazar *et al.* (1996). Atlantic cod: Sakhno & Sadokhin (1982); Netzel & Zaucha (1989); Isaksen & Valdemarsen (1990); Isaksen *et al.* (1990); Hickey *et al.* (1993); Lowry *et al.* (1995); Huse *et al.* (1996); Tschernij *et al.* (1996); Halliday *et al.* (1999); Tschernij & Holst (1999); Blady & Zaucha (2000); Wienbeck & Dahm (2000); Halliday (2002); Madsen *et al.* (2002); Graham *et al.* (2004); He (2007); Grimaldo *et al.* (2008). Haddock: Sakhno & Sadokhin (1982); Robertson & Stewart (1988); Isaksen *et al.* (1990); Reeves *et al.* (1992); Sangster & Lehmann (1994); Halliday *et al.* (1999); Halliday (2002); Graham *et al.* (2004); He (2007); Grimaldo *et al.* (2008). Blue whiting: Campos *et al.* (2003a); Campos *et al.* (2003b); Sala & Lucchetti (2010); Tokaç *et al.* (2010). Pollock (saithe): Smolowitz (1983); Dahm (1998) y Graham *et al.* (2004).

$q = \frac{p_1}{p_2}$ is the rate of sampling proportions in the codend and cover, respectively. The selectivity parameters v_1^* and v_2 of the logistic curve were estimated by means of haul-by-haul maximum likelihood using the CC2000 software (ConStat).

The 50% retention length (l_{50}) and the selection range (SR) were estimated as $l_{50} = -\frac{v_1}{v_2}$ and $SR = \frac{2\ln(3)}{v_2}$, respectively. The model proposed by Fryer (1991) was then used to investigate the between-haul variation of the selectivity parameters v_1^* and v_2 for each configuration, thereby allowing an average curve to be estimated for the codends. Analysis was done using the ECModel software (ConStat) based on the residual maximum likelihood (REML) method proposed by Fryer (1991). The individual contri-

Table 1. Summary of hauls and explanatory variables used in the Chilean hake selectivity experiments. Subsampling proportions by compartment (codend and cover) are also included.

Tabla 1. Resumen de los lances y variables explicatorias usados en los experimentos de selectividad de la merluza chilena. Las proporciones de submuestreo por compartimento (copo y cubrecopo) también son incluidas.

Haul	Mesh size (mm)	Depth (m)	Speed (knots)	Duration (min)	Codend						Cover						*q*
					Catch (kg)	Sample (n)	Av. length (cm)	Av. weight (kg)	Catch (n)	p1	Catch (kg)	Sample (n)	Av. length (cm)	Av. weight (kg)	Catch (n)	p2	
1	100	209	3.3	45	2737	149	49.27	0.861	3177	0.046	115	145	37.03	0.367	313	0.463	0.099
2	100	227	3.3	84	4426	110	46.68	0.733	6036	0.018	69	61	36.03	0.339	204	0.299	0.060
3	100	200	3.3	55	10999	85	48.91	0.842	13056	0.006	58	97	25.46	0.121	477	0.203	0.029
4	100	205	3.2	59	6253	98	49.66	0.881	7091	0.013	69	77	34.72	0.303	227	0.339	0.038
5	100	146	3.3	25	1698	109	46.83	0.739	2293	0.047	69	88	34.34	0.293	235	0.374	0.125
6	100	144	3.2	35	4320	144	46.55	0.727	5938	0.024	69	145	33.74	0.278	247	0.587	0.040
7	100	143	3.3	20	8996	321	43.73	0.604	14894	0.021	184	460	28.93	0.176	1043	0.441	0.047
8	100	158	3.2	19	10725	304	40.07	0.465	23048	0.013	184	304	34.89	0.308	597	0.509	0.025
9	100	217	3.3	45	2543	50	48.36	0.814	3121	0.016	46	28	38.46	0.411	112	0.251	0.064
1	110	200	3.9	84	1526	122	43.32	0.587	2598	0.046	23	55	33.72	0.278	83	0.662	0.069
2	110	175	3.6	45	4909	229	43.91	0.611	8035	0.028	1150	152	35.53	0.325	3534	0.043	0.651
3	110	165	4.0	44	1529	132	41.24	0.507	3016	0.043	23	92	29.16	0.179	127	0.724	0.059
4	110	220	3.7	24	14606	102	46.36	0.718	20328	0.005	23	77	27.12	0.145	158	0.487	0.010
5	110	100	3.7	120	3884	377	45.33	0.672	5778	0.065	276	577	28.95	0.176	1561	0.369	0.176
6	110	98	3.7	39	10508	316	46.81	0.739	14207	0.022	161	241	37.34	0.377	427	0.564	0.039
7	110	93	3.7	40	1776	181	46.87	0.742	2392	0.075	92	282	26.51	0.135	677	0.416	0.180
8	110	90	3.2	14	730	91	47.14	0.755	967	0.094	23	232	21.12	0.069	333	0.696	0.135

Haul	Mesh size (mm)	Depth (m)	Speed (knots)	Duration (min)	Codend						Cover						q
					Catch (kg)	Sample (n)	Av. length (cm)	Av. weight (kg)	Catch (n)	p1	Catch (kg)	Sample (n)	Av. length (cm)	Av. weight (kg)	Catch (n)	p2	
1	130	138	4.0	45	4656	445	41.96	0.534	8718	0.051	460	449	36.71	0.358	1284	0.349	0.146
2	130	132	4.0	90	3196	585	40.03	0.463	6889	0.084	644	462	35.75	0.331	1944	0.237	0.354
3	130	136	3.1	55	1736	592	39.29	0.438	3955	0.149	460	378	36.37	0.348	1319	0.286	0.520
4	130	135	3.2	105	5194	374	41.53	0.517	10031	0.037	1288	361	35.67	0.329	3914	0.092	0.402
5	130	139	3.3	69	3588	358	41.97	0.534	6714	0.053	598	361	34.49	0.297	2007	0.179	0.296
6	130	188	3.1	40	3442	305	45.97	0.701	4913	0.062	276	192	40.92	0.495	557	0.344	0.180
7	130	200	3.1	120	26510	298	46.17	0.709	37345	0.007	483	263	40.52	0.481	1004	0.261	0.026
1	140	147	3.2	65	6024	245	46.26	0.714	8436	0.029	2438	259	38.89	0.425	5724	0.045	0.644
2	140	159	3.3	110	7484	281	47.95	0.794	9417	0.029	4278	304	38.31	0.407	10507	0.028	1.035
3	140	184	3.0	135	6736	249	49.67	0.882	7633	0.032	2406	216	44.38	0.631	3812	0.056	0.571
4	140	260	3.1	50	895	112	48.83	0.839	1067	0.104	92	83	45.18	0.665	138	0..601	0.173
5	140	134	3.2	45	288	81	45.02	0.658	437	0.185	749	233	36.63	0.356	2103	0.109	1.681
6	140	130	3.2	45	5417	203	48.91	0.842	6428	0.031	699	211	40.72	0.488	1432	0.147	0.210
7	140	135	3.1	64	6585	220	47.11	0.753	8741	0.025	845	226	40.12	0.467	1809	0.124	0.201
8	140	185	3.2	90	4518	191	51.84	1.002	4506	0.042	311	188	45.27	0.669	465	0.404	0.103

butions of various explanatory variables to the selectivity parameters were tested using the ECModel according to the REML method (Fryer, 1991). The variables considered were mesh size, catch (in number and weight), tow duration, depth and towing speed. The choice of the best fit model was based on the lowest value for Akaike's Information Criterion (AIC) (Fryer & Shepherd, 1996).

RESULTS

To calculate the sample weight in each compartment (codend and cover), the length-weight relationship $w_i = 7.76e^{-6} l_i^{2.979}$ (R^2=0.97) was used for both sexes. The catch in numbers for each haul was calculated using this relationship and the catch weight. The resulting values ranged between 437 and 37,345 specimens in the codend and between 83 and 10,507 in the cover (Table 1). The corresponding sample proportions (p_1 and p_2) varied between 0.005 and 0.185 in the codend and between 0.028 and 0.724 in the cover. Accordingly, the relationship between the sample proportions (q) ranged between 0.01 and 1.68 ($\overline{q}$ =0.26). The q values for all hauls were taken into account in order to fit the selectivity models.

Fig. 2 shows the fitted curves for each haul. For all hauls, the estimated model resulted in good fits (P > 0.05) (Table 2). With the selection parameters v_1^* and v_2 taken into consideration in the haul-by-haul analysis, the resulting estimates of l_{50} ranged between 26.4 and 35.6 cm for the 100 mm mesh; between 22.9 and 35.4 cm for the 110 mm mesh; between 23.7 and 34.0 cm for the 130 mm mesh and between 35.3 and 45.6 cm for the 140 mm mesh. Using the fit of the average curve based on between-haul variation, values of l_{50} were estimated as 30.8, 29.9, 30.0 and 41.2 cm for each mesh size, respectively (Table 2). Selection range (SR) tended to increase with increasing mesh size. However, the 130 mm mesh exhibited a value higher than expected from the general tendency observed. The average values of SR were 6.9, 7.2, 11.9 and 8.3 cm for the 100, 110, 130 and 140 mm meshes, respectively (Table 2).

Addition of the explanatory variables to account for between-haul variation indicated that the parameter v_1^* depends significantly on the catch in numbers (P = 0.01) and the towing speed (P = 0.023), whereas v_2 depends on the mesh size (P < 0.001) (Table 3). This analysis yields a direct relation between l_{50} and the mesh size. On the other hand, the l_{50} value decreases as catch and towing speed increase. The model that best described selectivity was:

$$E\begin{pmatrix} v_1 \\ v_2 \end{pmatrix} = \begin{pmatrix} \alpha_1 + \alpha_3 c_i + \alpha_4 s_i \\ \alpha_2 + \alpha_5 m_i \end{pmatrix}$$

where c_i is the catch (in numbers), s_i is the towing speed (knots) and m_i is the mesh size (mm). The depth and duration variables did not contribute significantly to the model.

The effect of the catch for each mesh size used in the model was analysed for a range of 1,000 to 35,000 specimens caught and for a fixed towing speed corresponding to the average value of 3.4 knots. A significant decrease of at least 6 cm TL in the l_{50} value for extreme catches was observed for all mesh sizes (Fig. 3). For example, the l_{50} of the 100 mm mesh was 29.9 cm for a small catch (1,000 specimens), while this value decreases to 23.1 cm for a large catch (35,000 specimens).

Likewise, the model with towing speeds between 3 and 4 knots was evaluated assuming a constant catch of 10,000 individuals. A decrease of at least 4.5 cm TL in the l_{50} value for extreme speeds was observed (Fig. 4). For the 140 mm mesh at a towing speed of 3 knots, the l_{50} was 39.0 cm. This value decreased to 33.1 cm for a towing speed of 4 knots.

Note that v_2 depends only on the mesh size. Accordingly, the SR values estimated using the model were 7.2, 7.7, 8.9 and 9.6 cm for the meshes of 100, 110, 130 and 140 mm, respectively.

DISCUSSION

This study was based on the same data used by Gálvez & Rebolledo (2005). However, the results of the two studies differ (Fig. 5). The main analytic difference is that these authors assume that the sampling proportions in the codend and in the cover are equal. This assumption leads to a significant overestimation of the selectivity parameters. When this effect and the between-haul variation are both taken into account, the l_{50} estimate decreased by 9 cm for the 100, 110 and 130 mm mesh. The difference is lower (~4 cm) in the 140 mm mesh (Fig. 5).

Incorporation of subsampling effects produced a high dispersion of the l_{50} values. This effect is the result of other variables included in the selection process. This consideration led us to introduce explanatory variables to the model and by including the mesh size, the catch (in numbers) and the towing speed, it was possible to achieve significant reductions in the dispersion of the estimates (Fig. 5). The effect

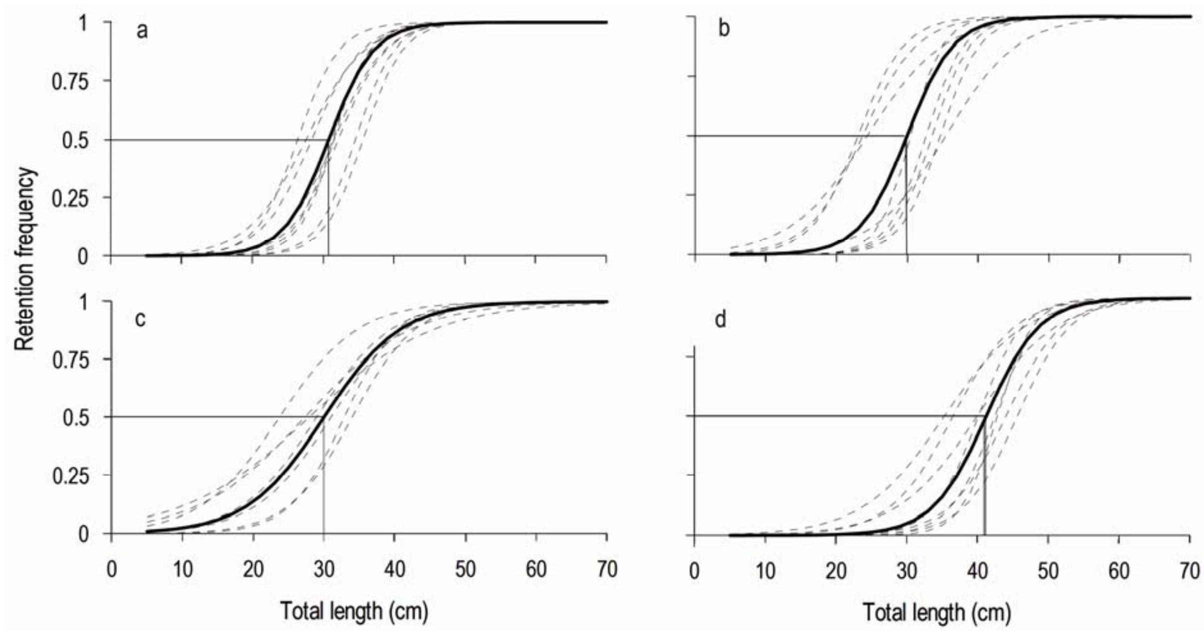

Figure 2. Chilean hake individual-haul selection curves (dotted lines) for each mesh size. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm. Each set of selection curves have been summarized by a mean selection curve (thick line) fitted using between-haul variation model of Fryer (1991).

Figura 2. Curvas de selección de la merluza chilena a cada lance (líneas segmentadas) para cada tamaño de malla. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm. Cada grupo de curvas de selección fue resumida mediante una curva de selección (línea gruesa) ajustada usando el modelo de variación entre lances de Fryer (1991).

of catch size on codend selectivity has been discussed in numerous studies. Some authors find that increasing catch size reduces l_{50} (Ehrhardt *et al.*, 1996; Erickson *et al.*, 1996; Tschernij & Holst, 1999; Madsen *et al.*, 2002; Grimaldo *et al.*, 2007). However, others have obtained the opposite result (O'Neill & Kynoch, 1996; Dahm *et al.*, 2002), while emphasising that selectivity tends to decrease when the catch size is very high. On the other hand, the studies of Madsen *et al.* (1998), O'Neill *et al.* (2006) and Grimaldo *et al.* (2008) yielded inconclusive results or found only a weak effect of the catch variable.

Many different factors are involved in gear selectivity. For example, alterations in and obstruct-tions of the escape channels can be produced, and changes can also occur in the tension-deformation relation of the meshes. Indeed, Erickson *et al.* (1996) point out that large catch sizes can obstruct the codend meshes and thereby reduce the potential escape channels for fish. Additionally, in some Gadidae, haddock and whiting for example, "opportunistic escape" is more common than "active escape" (Jones *et al.*, 2008). This difference results in a reduced probability of escape as the catch size increases. Tension-deformation is also an important factor. The increased size of the mesh opening and the change in the shape of the codend would both favour increased selectivity (O'Neill & Kynoch, 1996; Herrmann, 2005; Madsen, 2007). Nevertheless, the increased drag produced by the operation of the trawl can increase the tension on the mesh bars. This increased tension can make escape more difficult (O'Neill *et al.*, 2005) or can injure fish, thereby conditioning their post-escape survival (Suuronen, 2005).

Increased trawl speed thus affects selectivity adversely for two different reasons. Increased speed increases the resistance encountered by the gear, raises the tension on the codend meshes, and consequently reduces the mesh opening (Dahm *et al.*, 2002; O'Neill *et al.*, 2005). On the other hand, an increase in trawl speed also reduces the swimming performance of fish (Dahm *et al.*, 2002; Breen *et al.*, 2004). In this study, we did not have enough information to identify a particular mechanism responsible for the l_{50} decrease. However, Queirolo *et al.* (2010) noted in hake that when fish are close to the codend at a towing speed of 4 knots, most fish exhibit no movement, appear exhausted and drop back into the codend.

The model obtained in this study indicates that the selectivity decreases as the catch size increases. This effect could be explained by the obstruction of the escape channels and by the closure of the meshes due to the increase of the tension. In the model, selectivity

Table 2. Analysis of the Chilean hake selectivity by bottom trawls. The SELECT (Share Each Length Catch Total) model estimates of the selection parameters (v_1^* and v_2) for each haul. The within-haul variance, goodness of fit statistics, mean curve estimated by using between-haul variation (Fryer, 1991). Estimates of l_{50} and selection range (SR) are also given.

Tabla 2. Análisis de la selectividad de la merluza chilena por redes de arrastre de fondo. Estimados del modelo SELECT de los parámetros de selección (v_1^* and v_2) para cada lance. Se presenta también la variación intra lance, los estadísticos de bondad de ajuste, la curva media estimada usando variación entre lances (Fryer, 1991) y los estimados de l_{50} y rango de selección (SR).

Haul	Mesh size	v_1	v_2	var(v_1)	var(v_1.v_2)	var(v_2)	Deviance	dof	*P*-value	l_{50}	SR
1	100	-12.96	0.36	2.8528	-0.0685	0.0017	23.37	39	0.98	35.62	6.04
2	100	-6.73	0.24	2.4762	-0.0601	0.0015	24.08	33	0.87	27.56	9.00
3	100	-11.73	0.38	5.8228	-0.1398	0.0034	25.60	45	0.99	31.27	5.86
4	100	-8.94	0.28	3.5168	-0.0788	0.0018	28.61	39	0.89	31.52	7.74
5	100	-9.56	0.30	2.6499	-0.0681	0.0018	28.11	35	0.79	32.11	7.38
6	100	-12.70	0.40	3.2103	-0.0832	0.0022	19.75	36	0.99	31.50	5.45
7	100	-8.09	0.29	0.7791	-0.0203	0.0005	22.90	39	0.98	28.37	7.70
8	100	-9.12	0.35	1.8463	-0.0504	0.0014	15.78	33	1.00	26.39	6.36
9	100	-12.80	0.37	9.9798	-0.2283	0.0053	20.03	20	0.46	34.55	5.93
Mean curve (Fryer)		-9.75	0.32	2.2042	-0.0361	0.0009				30.79	6.94
1	110	-13.43	0.44	7.4438	-0.1995	0.0054	33.83	25	0.11	30.43	4.98
2	110	-6.96	0.20	0.7907	-0.0201	0.0005	41.06	32	0.13	35.36	11.16
3	110	-6.15	0.26	2.2284	-0.0618	0.0017	20.66	37	0.99	23.60	8.43
4	110	-7.07	0.31	3.4963	-0.0882	0.0023	18.33	40	1.00	22.97	7.14
5	110	-12.43	0.37	0.7251	-0.0194	0.0005	42.33	45	0.59	33.45	5.92
6	110	-4.47	0.18	0.6554	-0.0146	0.0003	30.05	45	0.96	24.25	11.92
7	110	-12.46	0.36	1.7202	-0.0419	0.0011	19.55	43	1.00	34.60	6.10
8	110	-12.32	0.38	4.7162	-0.1173	0.0030	18.22	41	1.00	32.61	5.82
Mean curve (Fryer)		-9.07	0.30	10.6178	-0.2463	0.0069				29.90	7.24
1	130	-5.47	0.19	0.4096	-0.0104	0.0003	9.19	35	1.00	28.95	11.63
2	130	-5.86	0.19	0.4315	-0.0115	0.0003	32.11	34	0.56	30.99	11.61
3	130	-3.14	0.11	0.3357	-0.0089	0.0002	38.94	35	0.30	27.89	19.53
4	130	-7.61	0.22	0.6221	-0.0164	0.0004	30.96	36	0.71	33.98	9.81
5	130	-8.67	0.26	0.6926	-0.0187	0.0005	24.25	39	0.97	32.85	8.33
6	130	-3.60	0.13	0.6452	-0.0145	0.0003	35.06	33	0.37	27.29	16.67
7	130	-4.29	0.18	0.7302	-0.0164	0.0004	15.72	30	0.99	23.71	12.15
Mean curve (Fryer)		-5.53	0.18	3.5308	-0.0858	0.0023				30.00	11.92
1	140	-7.08	0.18	0.5382	-0.0127	0.0003	16.40	35	1.00	39.91	12.38
2	140	-13.76	0.32	1.1333	-0.0270	0.0007	21.72	38	0.98	42.44	6.78
3	140	-11.04	0.25	1.7664	-0.0377	0.0008	21.09	35	0.97	43.99	8.76
4	140	-6.16	0.17	3.7661	-0.0797	0.0017	15.64	24	0.90	35.27	12.58
5	140	-12.21	0.27	1.5847	-0.0392	0.0010	35.17	27	0.13	45.60	8.20
6	140	-12.83	0.32	1.8690	-0.0410	0.0009	29.24	34	0.70	40.10	6.87
7	140	-8.26	0.23	0.9884	-0.0224	0.0005	22.55	33	0.91	36.50	9.71
8	140	-17.13	0.40	5.2595	-0.1082	0.0022	15.10	35	1.00	42.78	5.49
Mean curve (Fryer)		-10.96	0.27	10.2228	-0.2080	0.0044				41.20	8.26

Table 3. Analysis of the Chilean hake selectivity by bottom trawls. Contribution of explanatory variables on the selection parameters; alpha parameter estimates, standard deviation, *t*-value, degrees of freedom (dof) and *P*-value.

Tabla 3. Análisis de la selectividad de la merluza chilena por redes de arrastre de fondo. Contribución de variables explicatorias en los parámetros de selección; estimados del parámetro alpha, desviación estándar, valor *t*, grados de libertad (dof) y valor *P*.

Parameter	Estimate	Standard deviation	*t*-value	dof	*P*-value
α_1 (v_1, intcpt)	-13.970	2.098	-6.66	56	<0.001
α_2 (v_2, intcpt)	4.886×10^{-1}	3.219×10^{-2}	15.18	56	<0.001
α_3 (v_1, catch)	5.713×10^{-5}	2.145×10^{-5}	2.66	56	0.010
α_4 (v_1, speed)	1.363	5.843×10^{-1}	2.33	56	0.023
α_5 (v_2, mesh size)	-1.850×10^{-3}	2.401×10^{-4}	-7.72	56	<0.001

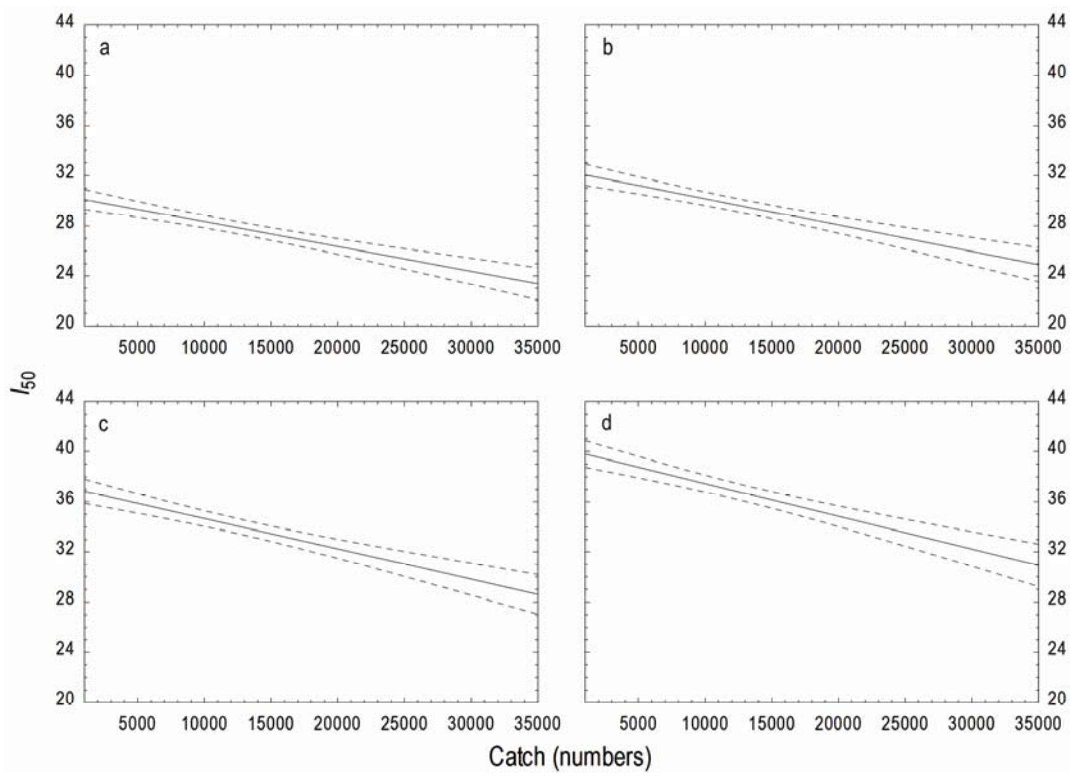

Figure 3. Analysis of the Chilean hake selectivity by bottom trawls. Regression lines with 95% confidence bands for the 50% retention length (l_{50}) depending on the catch size in the codend (in numbers) for each mesh size. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm.

Figura 3. Líneas de regresión con bandas de confianza al 95% para la longitud de retención al 50% (l_{50}) según el volumen de captura en el copo (en número) para cada tamaño de malla. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm.

also decreased with increased towing speed. This effect can be attributed to the lower swimming performance of the fish. The significance found for the explanatory variables in the selectivity model indicates that these variables could be included in management "good practices" recommendations for users. Although the tow duration was not significant in our results, we recognize that this variable plays an important role both during the escape phase and post-escape survival (Suuronen, 2005), so it should be consider in subsequent studies.

In order to reduce the juvenile catch and avoid growth overfishing, the recommended value of l_{50} should be greater than or equal to the size at sexual maturity estimated as 34 cm TL by Lillo *et al.* (2009). Likewise, assuming an average catch of 10,000 fish

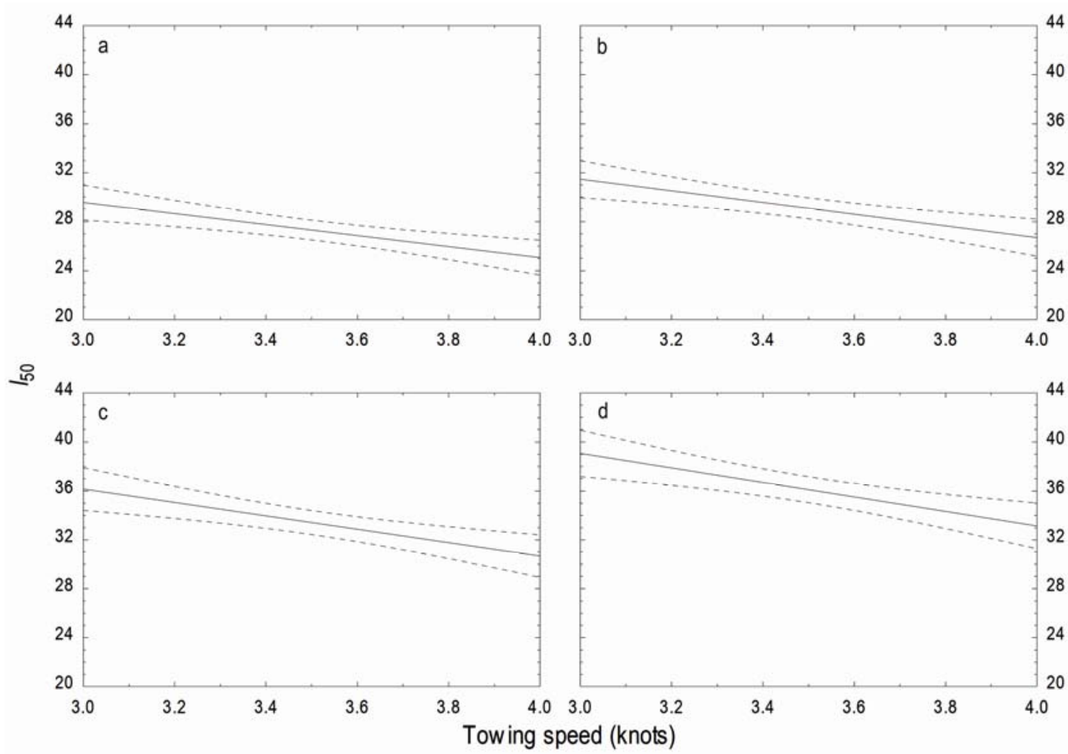

Figure 4. Analysis of the Chilean hake selectivity by bottom trawls. Regression lines with 95% confidence bands for the 50% retention length (l_{50}) depending on the towing speed (knots) for each mesh size. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm.

Figura 4. Líneas de regresión con bandas de confianza al 95% para la longitud de retención al 50% (l_{50}) según la velocidad de arrastre (nudos) para cada tamaño de malla. a) 100 mm, b) 110 mm, c) 130 mm, d) 140 mm.

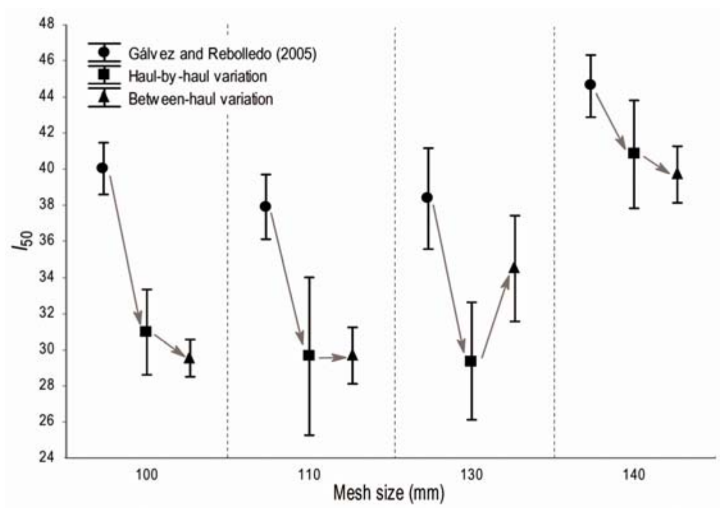

Figure 5. Analysis of the Chilean hake selectivity by bottom trawls. Comparison of the 50% retention length (l_{50} in cm) estimates (and their confidence intervals) obtained by three different approaches: i) Haul-by-haul estimation without no considering the sampling proportions (Gálvez & Rebolledo, 2005), ii) haul-by-haul considering sampling proportions (present work), iii) between-haul variation considering the sampling proportions and the effect of the explanatory variables (present work).

Figura 5. Análisis de la selectividad de la merluza chilena por redes de arrastre de fondo. Comparación de los estimados de retención al 50% (l_{50} in cm) (y sus intervalos de confianza) obtenidos mediante tres diferentes aproximaciones: i) estimación lance a lance sin considerar las proporciones de muestreo (Gálvez & Rebolledo, 2005), ii) lance a lance considerando las proporciones de muestreo (presente trabajo), iii) variación entre lances considerando proporciones de muestreo y el efecto de variables explicatorias (presente trabajo).

and an average towing speed of 3.4 knots, an estimate of the minimum mesh size recommended for the fishery is 125 mm. However, at present, the use of 100 mm mesh and a 90-mm square mesh panel are mandatory (see Queirolo *et al*., 2008). For this reason, it is fundamental to evaluate and compare the whole selectivity of these codends for the fishery. These recommendations demonstrate ways in which the addition of the subsampling effect and the use of explanatory variables to model between-haul variation can allow fisheries scientists to improve selectivity estimates for Chilean hake.

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